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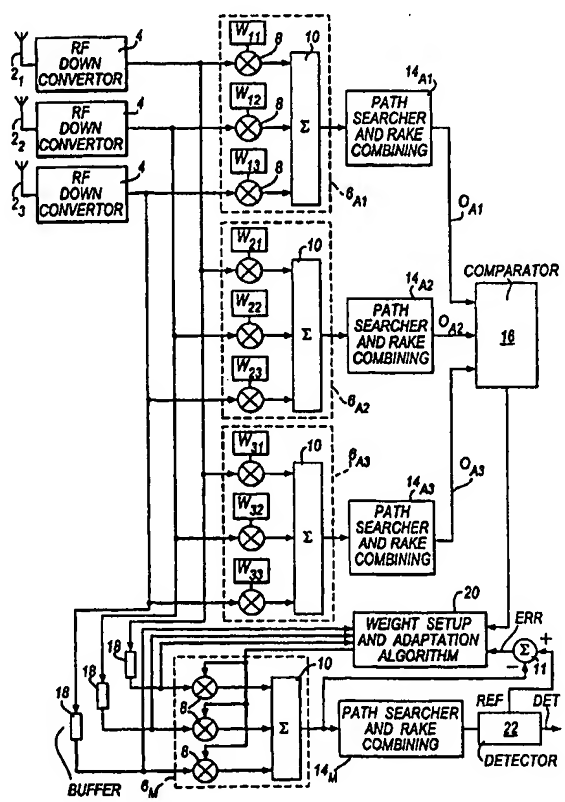
(57) Abstract

Receiving apparatus, for receiving a transmission signal in a cellular mobile communications system, comprises a main beamformer (6M, 14M) which processes received signals, representing the said transmission signal, in accordance with a main beam pattern. This main beam pattern is determined by beam control information applied to the main beamformer. The main beam pattern is adjusted as necessary during use of the receiving apparatus to facilitate reception of the said transmission signal.



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RECEIVING APPARATUS INCLUDING ADAPTIVE BEAMFORMERS

The present invention relates to receiving apparatus including adaptive beamformers. In particular, the present invention can provide receiving apparatus for use in a base station of a cellular mobile communication system.

In a cellular mobile communications system, one of the main tasks of the base station is to detect the signal of each wanted user (i.e. each active mobile station) in a multi-user and multi-path environment. In order to achieve satisfactory signal detection at low bit error rates, two conditions must be satisfied. Firstly, the power level of the signal received by the base station from the mobile station must be greater than a certain threshold value. Secondly, the multi-user interference (MUI), sometimes referred to also as multiple access interference (MAI), must be reduced to an acceptable level.

To satisfy the two conditions identified above, it is effective to use adaptive beamformers in general and digital beamformers in particular. The principle underlying a digital beamformer is to form a spatial beam pattern in such a way that the angles of arrival of wanted signals fall well within a main lobe of the beam pattern whereas the interfering signals are located as much as possible in the nulls, low side lobes or boundary regions of the main lobe.

Figure 1 of the accompanying drawings shows parts of a previously-considered digital beamformer. A plurality of independent sensors (antenna elements 2_1 to 2_4) are provided to detect, at different points in space, a transmission signal sent to the base station by a mobile unit (not shown in Figure 1). The antenna elements 2_1 to 2_4 permit sampling of the received signal in space. The respective receive signals

produced by the antenna elements 2_1 to 2_4 are digitised (e.g. by RF down-converters not shown) and then applied to the digital beamformer 6 which is employed as a spatial filter.

The digital beamformer 6 includes a set of complex number multipliers 8 connected respectively for receiving the different antenna signals. Each complex number multiplier multiplies its antenna signal by a weight value W set by a weight setting unit 12 of the beamformer 6. The resulting outputs of the multipliers 8 are then combined by a combiner 10 to produce an output signal of the digital beamformer. The object of the spatial filtering carried out by the digital beamformer 6 is to optimise the beam former response with respect to some prescribed criterion so that noise and interference are minimised in the output signal.

A subtractor 11 subtracts a reference signal from the output signal of the digital beamformer to produce an error signal. The weight setting unit 12 receives the error signal and the receive signals from the antenna elements 2_1 to 2_4 and processes them to derive the weight values W_1 to W_4 applied to the complex number multipliers 8.

In a steady-state condition, in which the wanted and interfering signals each have a fixed angle of arrival at the receiving apparatus, there will be a fixed optimum set of beamformer weight values W_1 to W_4 which satisfies the prescribed criterion for minimising noise and interference at the output of the beam former. An adaptation algorithm is employed in the weight setting unit 12 which, in the above steady-state condition, would cause the weight values to converge to their optimum steady-state values and, thereafter, the noise and interference at the output of the beamformer would remain at a minimum level related to the number of weights. However, in practice, multi-path

propagation means that the transmission channel between the subject mobile unit and the base station is time-variant and, furthermore, the positions of the interfering signal sources (for example other mobile stations) will change, with respect to one another and the base station, over time. Accordingly, using its adaptation algorithm, the weight setting unit 12 is required to update the beamformer weight values continuously in accordance with the changing operating parameters.

Incidentally, further information about digital beamforming techniques and related adaptive algorithms can be found, for example, in "Digital beamforming in wireless communications", John Litra and Titus Kwok-Yeung Lo, Artech House Publishers, 1996, ISBN: 0-89006-712-0, the content of which is incorporated herein by reference.

In practice, when a base station is expecting to receive a signal from a wanted user, it initially has no idea of the direction from which that signal will come. Thus, it is inappropriate to point the initial beam pattern, which is determined by the initial weight setting of the digital beamformer, to any particular direction. However, if an omnidirectional initial beam pattern is used, the level of the MUI can be so high that it takes a long time for the adaptation algorithm to converge, which inevitably leads to long delay and/or waste of bandwidth.

A paper entitled "An adaptive array antenna using combined DFT and LMS Algorithm" by K Watanabe, I Yoshii, and R Johno, Annual EIT Conference of Telecommunications, 1997, discloses a two-stage approach for determining beam directions in a TDMA communications system. In the first stage, in place of a digital beamformer (weighted summing circuit) discrete fourier transform (DFT) processing is applied

to the received signals so as to effectively form plural fixed beams. The results of the DFT processing are used to establish the initial weight factors for the second stage which involves Least Mean Square (LMS) processing of the received signals. This two-stage approach is partially effective in improving the convergence of the beamformer weights. However, it suffers from the following serious limitations. Firstly, it is necessary for all the beams formed during DFT processing to be produced simultaneously, making the hardware construction of the receiving apparatus expensive. Secondly, the number of fixed beams is limited to being no greater than the number of antenna elements. Thirdly, there is no control over the beam shapes and pointing directions during the DFT processing. In particular, there is no freedom in choosing the "look-directions" of the antenna elements and the parameter d/λ independently (d is the inter-element spacing and λ is the operating wavelength). This lack of control effectively limits the DFT approach to use in switched beam and multi-beam antennas only when the beams are pointed to certain directions and no sidelobe control is needed. In practice the antenna elements must therefore be evenly spaced and placed on a plane. Fourthly, the DFT approach is not fully effective in the case in which two or more of the fixed beams provide comparably-good signals.

Accordingly, it is desirable to provide a technique which enables the base station beamformer to set up its initial weights quickly, thus reducing the convergence time and the demand for long pilot signals, without the limitations mentioned above.

According to a first aspect of the present invention there is provided receiving apparatus, for receiving a transmission signal in a cellular mobile

communications system, comprising: main beamformer means operable to process received signals, representing the said transmission signal, in accordance with a main beam pattern that is determined by beam control information applied thereto, the said main beam pattern being adjusted as necessary during use of the receiving apparatus to facilitate reception of the said transmission signal; assistant beamformer means operable, in an initial operating phase of the apparatus, to process such received signals in accordance with each one of a plurality of different assistant beam patterns to derive one or more output signals corresponding to the assistant beam pattern concerned, each such pattern being determined by beam control information corresponding individually thereto; and beam control information setting means operable to employ the said output signals and the said beam control information corresponding respectively to the said assistant beam patterns to make an initial estimate of the said beam control information for the said main beamformer means.

According to a second aspect of the present invention there is provided a method of receiving a transmission signal in a cellular mobile communications system, in which received signals representing the said transmission signal are processed in accordance with a main beam pattern that is determined by beam control information corresponding thereto, and the main beam pattern is adjusted as necessary to facilitate reception of the said transmission signal; the method including an initialisation step of: processing such received signals in accordance with each one of a plurality of different assistant beam patterns to derive one or more output signals corresponding to the assistant beam pattern concerned, each such pattern being determined by beam control information

corresponding individually thereto; and employing the said output signals and the said beam control information corresponding respectively to the said assistant beam patterns to make an initial estimate of the said beam control information corresponding to the said main beam pattern.

In receiving apparatus and a receiving method embodying the present invention fast convergence of the beam control information (weight values) for the main beamformer is achieved reliably without the limitations inherent in the above-mentioned two-stage DFT and LMS approach. In particular, the same assistant beamformer can, if desired, be used in serial fashion to form the fixed beams (assistant beam patterns), leading to cost savings. The number of assistant beam patterns can also be greater than the number of antenna elements (received signals). Because each assistant beam pattern is determined by its own individually-corresponding beam control information (weight values) the pointing directions, shapes and widths of the assistant beamformers can be optimally controlled and independently designed according to demand. For example, it may be desired to change the assistant beam patterns from time to time in the course of a 24-hour period to cater for different traffic conditions. Also, each base station site is unique and so it is important to have total freedom in choosing the assistant beam patterns independently of one another. Furthermore, the antenna elements can be unevenly spaced and do not need to be placed uniformly in a single plane.

Reference will now be made, by way of example, to the accompanying drawings, in which:

Figure 1, discussed hereinbefore, shows parts of a previously-considered digital beamformer;

Figure 2 is a block diagram showing parts of

receiving apparatus according to a first embodiment of the present invention;

Figure 3 shows a further block diagram showing, in more detail than Figure 2, parts of the first embodiment;

Figure 4 is a graph showing one example of beam patterns produced by the first embodiment of the present invention;

Figure 5 is a block diagram showing parts of receiving apparatus according to a second embodiment of the present invention;

Figure 6 shows a waveform diagram for use in explaining operation of the second embodiment;

Figure 7 is a block diagram showing parts of receiving apparatus according to a third embodiment of the present invention;

Figure 8 shows a waveform diagram for use in explaining operation of the third embodiment;

Figure 9 is a block diagram showing parts of receiving apparatus according to a fourth embodiment of the present invention;

Figure 10 is a block diagram showing parts of receiving apparatus according to a fifth embodiment of the present invention; and

Figure 11 is a waveform diagram for use in explaining communications between a mobile station and a base station at the time a channel is first activated.

Figure 2 shows parts of receiving apparatus according to a first embodiment of the present invention. This embodiment is intended for use in a cellular mobile communications system which combines pilot-symbol-assisted modulation (PSAM) with direct-sequence code-division-multiple-access (DS-CDMA). This DS-CDMA PSAM system may, for example, have the following specification:

Modulation method - quadrature phase shift keying (QPSK), pilot-symbol-assisted coherent detection;

Chip rate = 4.096 Mchips/s;

Symbol rate = 32 kbits/s.

In such a CDMA system, a pseudo-noise (PN) spreading code is used to spread the transmission signal at the mobile station. This spreading code is known to the receiving apparatus, enabling it to decode (or despread) the spread transmission signal received from the mobile station. Further information on spreading and despreading in DS-CDMA systems can be found, for example, in "CDMA - principles of spread spectrum communications", Andrew J Viterbi, Addison-Wesley Publishing Co., 1995, ISDN: 0-201-63374-4, the content of which is incorporated herein by reference.

In a PSAM system, known pilot symbols are periodically inserted into the user data stream for the purposes of obtaining channel information. The receiving apparatus is able to estimate the attenuation and phase rotation for each of the received pilot symbols, which provides a mechanism for compensation of the fading envelope and phase. Further information on PSAM may be found, for example, in "Modern quadrature amplitude modulation - principles and applications for fixed and wireless communications", William T Webb and Lajos Hanjo, Pentech Press and IEEE Press 1994/95, ISBN: 0-7273-1701-6, the content of which is incorporated herein by reference.

As shown in Figure 2 the receiving apparatus according to the first embodiment comprises three antenna elements 2_1 to 2_3 which are connected to respective RF down-converters 4. These RF down-converters are connected in turn to a set of beamformers 6.

This set of beamformers comprises respective first, second and third assistant beamformers 6_{A1} to

6_{A3}, and a main beamformer 6_M. Referring to Figure 2, the constitution of each of the beamformers 6_{A1}, 6_{A2}, 6_{A3} and 6_M can be seen. Each beamformer has essentially the same constitution as described above with reference to Figure 1. The beamformer has three digital inputs corresponding respectively to the three different antenna elements 2_1 to 2_3. In the case of the assistant beamformers 6_{A1} to 6_{A3}, each of these beamformer inputs is connected directly to the digital output of the RF down-converter 4 for its corresponding antenna element. In the case of the main beamformer 6_M, on the other hand, each beamformer input is connected to one of the RF down-converters via a buffer 18, the purpose of which will be described later.

The beamformer inputs in this embodiment are adapted to receive in phase and quadrature (I and Q) digital signal pairs.

The beamformer inputs are coupled to respective complex number multipliers 8 which also receive respective weight values. In the case of the assistant beamformers 6_{A1} to 6_{A3} the weight values W_{11} to W_{33} are fixed (predetermined). For the weight values W the first digit of the suffix denotes the number of the assistant beamformer and the second digit of the suffix denotes the number of the antenna element. Thus, for example, the weight value W_{12} is applied to the complex number multiplier 8 of the first digital beamformer 6_{A1} that is used to process the signal produced by the second antenna element 2_2.

In the case of the main beamformer 6_M, the weight values are variable (not fixed) and are adjusted as necessary during use of the apparatus. These weight values are supplied to the main beamformer 6_M by a weight setup and adaptation algorithm portion 20 (also described in more detail later).

Returning to Figure 2, the outputs of the first,

second and third assistant beamformers 6_{A1} to 6_{A3} are supplied to respective first, second and third path searcher and RAKE combiner portions 14_{A1} to 14_{A3}. The output of the main beamformer 6_M is supplied to a further path searcher and RAKE combiner portion 14_M. The output of the main beamformer 6_M is also connected to the negative input of a subtractor 11.

Respective output signals O_{A1}, O_{A2} and O_{A3} of the first, second and third path searcher and RAKE combiner portions 14_{A1} to 14_{A3} are applied to inputs of a comparator 16. A selection signal SEL produced by the comparator 16 is applied to an input of the above-mentioned weight setup and adaptation algorithm portion 20.

An output signal O_M of the main beamformer path searcher and RAKE combiner portion 14_M is applied to an input of a detector 22. The detector 22 produces a detection signal DET, representing the detected transmission signal from the mobile station, as well as a reference signal REF which is applied to a positive input of the subtractor 11. An error signal ERR produced by the subtractor 11 is applied to an input of the weight setup and adaptation algorithm portion 20.

Incidentally, it is also possible for the detection signal DET and the reference signal REF to be one and the same signal, depending on the adaptation algorithm embodied in the weight setup and adaptation algorithm portion 20.

Operation of the first embodiment described above with reference to Figure 2 will now be explained. In mobile communications environments, reflectors are inevitably present which lead to multi-path propagation of the transmission signal from the mobile station to the base station. These different paths will have different lengths and directions and, accordingly, the base station receives a succession of reflections of

the transmission signal which have different respective delays and angles of arrival. The path searcher and RAKE combiner portions 14 shown in Figure 2 having, for example, four fingers are intended to enable the receiver to lock on to the four best paths between the mobile station and the base station, i.e. the four strongest versions of the transmission signal, and to produce an output signal for each path.

When the base station is expecting to receive data from a wanted user (mobile station), the first, second and third assistant beamformers are activated to form a number of beam patterns ("assistant beam patterns") simultaneously, each assistant beam pattern effectively pointing to a predetermined direction in a specified sectorial range. The beam width of each assistant beam pattern should be large enough, for example greater than 15° for macrocells, to intercept most of the multi-path signals from any wanted user, as well as being well overlapped so that the signal from a wanted user in any direction will be received with a satisfactory power level.

By way of example, Figure 4 shows three assistant beam patterns covering a 60° sector. In Figure 4, the sector to be covered extends from -30° to +30°. The main beams of the three assistant beam patterns are centered respectively on -20°, 0° and +20°. According to this beam pattern arrangement, the intensity of the received signal from any user in the sector concerned will not be reduced by more than 2dB from its maximum value. Incidentally, in Figure 4, the low peaks (below -10dB) represent side lobes of the assistant beam patterns.

The assistant beam patterns are determined by the weight values W_{11} to W_{33} applied to the complex number multipliers 8 in the assistant beamformers concerned. In order to form a set of assistant beam patterns

pointed in different directions, the weights of the assistant beamformers can have the same magnitude distribution but different respective phase distributions. The magnitude distribution can be either uniform, which leads to a narrow main beam but high side lobes, or non-uniform such as the Taylor distribution, which leads to a wider main beam and low side lobes. Further information relating to how the beam patterns are determined can be found, for example, in "Phase array antenna handbook", RJ Mailloux, Artech House Publishers, 1994.

The respective digital signals (I-Q signal pairs) produced by the RF down-converters 4 of the different antenna elements 2_1 to 2_3 are multiplied, using the complex number multipliers 8, by the appropriate weight values and then combined by the combiner 10 to produce an output signal of the assistant beamformer concerned.

The path searcher and RAKE combiner portion 14_{A1} receives output signals from the first assistant beamformer and identifies the four best signals obtained within the assistant beam pattern formed by the first assistant beamformer.

Incidentally, it may be that, within that assistant beam pattern, there are not four acceptable signals. In this case, the path searcher and RAKE combiner portion 14_{A1} will deactivate one or more of its fingers so as to reduce noise and conserve power.

The signals selected by the path searcher are then combined appropriately in the portion 14_{A1} to produce a combined output signal O_{A1} for the first assistant beamformer.

The same operations are performed in parallel by the second and third path searcher and RAKE combiner portions 14_{A2} and 14_{A3}.

When the multi-path signals of a wanted user (mobile station) arrive at the base station, one or

possibly two of the path searcher and RAKE combiner portions 14_{A1} to 14_{A3} will produce the "best" output signal(s) (representation(s) of the wanted signal). The best signal(s) can be determined by reference to one or more of the following quality measures: the carrier-interference ratio (CIR) of each output signal O_{A1} to O_{A3}; the signal-noise and interference ratio (SNIR); the bit error rate (BER); and the signal strength (SS). It would also be possible to compare two or more measures in combination or in order of significance. For example, it would be possible to compare the CIR of the assistant beamformer output signals O_{A1} to O_{A3} first and then go on to compare the signal strengths of the output signals only if the CIR comparison alone is inconclusive.

If the result of the comparisons performed by the comparator 16 is that just one of the output signals clearly represents the best signal, the comparator 16 delivers to the weight setup and adaptation algorithm portion 20 a selection signal SEL identifying the assistant beamformer that produced that one signal.

If, however, two or more of the assistant beamformers produce comparably-good output signals, the selection signal SEL produced by the comparator 16 identifies each of the assistant beamformers concerned.

In the weight setup and adaptation algorithm portion 20, the selection signal SEL produced by the comparator 16 is analysed. If the selection signal identifies just one "best" output signal, the initial weight values of the main beamformer 6_M in each finger are simply made equal to the weight values of the assistant beamformer which produced that best signal. Thus, the main beam pattern is initially the same as the assistant beam pattern produced by that assistant beamformer.

If, on the other hand, the selection signal SEL

identifies two assistant beamformers as having produced comparably-good output signals, it follows that the signals of the wanted user are coming from somewhere between the directions of the two assistant beamformers concerned and an interpolation process is then used to produce the initial weight settings for the main beamformer. In this interpolation process, the initial direction of the main beam pattern can simply be set to halfway between the directions of the two assistant beam patterns. Alternatively, the two assistant beam patterns can be "weighted" in accordance with their respective output-signal quality measures (e.g. CIR, SNIR) to arrive at a predicted initial main beam pattern having direction intermediate between the respective directions of the two assistant beam patterns.

Incidentally, if desired, the interpolation process can be applied to more than two comparably-good output signals.

The initial weight settings arrived at by the weight setup and adaptation algorithm portion 20 are then supplied to the main beamformer 6_M, whereafter a normal adaptation process is started within the weight setting and adaptation algorithm portion 20. In this adaptation process the error signal ERR produced by the subtractor 11 is employed as a feedback signal, so that a feedback loop (including the path searcher and RAKE combiner portion 14_M, the detector 22 and the weight setup and adaptation algorithm 20) is created. By virtue of this feedback loop the initial main beam pattern is optimised and then updated dynamically to track the motion of the mobile station and channel variation, so as to optimise the main beamformer response with respect to some prescribed criterion (e.g. SIR).

When the adaptation process starts, the assistant

beamformers are released to perform a similar initial weight setting task, either for the same sector or for adjacent sectors.

As indicated previously, the down-converted antenna signals from the three different antenna elements 2_1 to 2_3 are applied to the main beamformer inputs by way of respective buffers 18. The delays introduced by these buffers are equal to or greater than the length (e.g. 60μs) of a batch of pilot symbols present in each timeslot of the transmission signal sent by the mobile station. For example, in a CDMA system, the transmission signal may be divided up into timeslots of 20 symbols, of which the first 4 symbols in the timeslot are pilot symbols and the remaining 16 symbols are user- data symbols or control symbols. The use of the buffers 18 permits the same batch of pilot symbols to be used first by the assistant beamformers to arrive at an initial weight setting for the main beamformer, and then to be used again by the main beamformer itself once set up with that initial weight setting.

The buffers can, if desired, be replaced by switches which are initially off during operation of the assistant beamformers and are then activated, once the initial weight determination for the main beamformers has been made, to connect the antenna signals to the main beamformer inputs. In this case, of course, the pilot symbols used by the assistant beamformers are not available to the main beamformer.

Figure 3 shows a modification to the first embodiment in which, in place of a common main beamformer 6_M for all RAKE fingers as in Figure 2, each "main beamformer" RAKE finger F1 to F4 has its own main beamformer 6_{M1} to 6_{M4}. In this case, as the main beamformer in each finger should be capable of operating independently of the other main beamformers,

the functions of the comparator 16 and weight setup and adaptation portion 20 in Figure 2 are redistributed in Figure 3. Thus, the comparator and weight setup functions are performed in the Figure 3 apparatus in a weight setup portion 20A and the adaptation function is performed separately in each finger with each finger having its own adaptation portion 20B.

As shown schematically in Figure 3, each "main beamformer" finger F1 to F4 includes its own main beamformer 6_{M1} to 6_{M4}, its own adaptation portion $20B_1$ to $20B_4$, its own subtractor 11_1 to 11_4 and its own despreader 141_1 to 141_4. A maximum ratio combiner (MRC) portion 142 is connected to receive respective outputs of the despreaders 141_1 to 141_4 in the four fingers. It will be appreciated that the despreaders 141_1 to 141_4 and the MRC portion 142 (together with other elements such as a path searcher, not shown) together make up the path searcher and RAKE combiner portion 14_M in Figure 2.

In Figure 3, the outputs of the assistant beamformers are coupled to respective path searcher portions $14'_{A1}$ to $14'_{A3}$ which do not have the RAKE combining function of the corresponding portions 14_{A1} to 14_{A3} in Figure 2. Each path searcher portion $14'_{A1}$ to $14'_{A3}$ functions only to identify the n best paths (n = 4, for example) within its corresponding assistant beam pattern and the best paths are not in this case combined to form one output signal per assistant beamformer as in the Figure 2 embodiment. Instead, in Figure 3 n output signals PO_{A1} corresponding respectively to the n best paths of the first assistant beamformer are applied to the weight setup portion 20A. Similarly, n output signals PO_{A2} corresponding respectively to the n best paths of the second assistant beamformer are applied to the weight setup portion 20A. Also, n output signals PO_{A3} corresponding

respectively to the n best paths of the third assistant beamformer are applied to the weight setup portion 20A.

In use of the Figure 3 apparatus, the assistant beamformers operate as described previously with reference to Figure 2, each of them having a differently-directed assistant beam pattern. For each assistant beam pattern, the n best paths are identified by the corresponding path searcher to produce a set of n per-path output signals for the assistant beam pattern concerned (the set PO_{A1} for the beamformer 6_{A1}, the set PO_{A2} for the beamformer 6_{A2} and the set PO_{A3} for the beamformer 6_{A3}). The output signals (3n in total) are received in the weight setup portion 20A which compares the output signals (according to one or more quality measures such as CIR, SNIR, BER, SS etc. as before) to determine the initial weights W_{I1} to W_{I4} for the main beamformers.

For example, it may be that a mobile station is located in a direction intermediate between the main lobe directions of two different assistant beamformers. In this case, some of the best paths are likely to fall within the main lobe of one of those two assistant beamformers whilst the remainder fall within the main lobe of the other of the two assistant beamformers. In such a case, rather than use interpolation to set the initial weights for a common main beamformer as in Figure 2, in the Figure 3 apparatus it is possible to set the initial weights for the main beamformers on a path-by-path basis. Thus, if two of the best paths fall within the assistant beam of the first assistant beamformer and the remaining two best paths fall within the assistant beam pattern of the third assistant beamformer, the initial weights (e.g. W_{I1} , W_{I2}) for two of the main beamformers can be made equal to the first-assistant-beamformer weights whilst the initial weights (W_{I3}, W_{I4}) for the other two main beamformers

are made equal to the third-assistant-beamformer weights.

After the initial weights for the different main beamformers have been selected the main beamformers operate independently for the different paths, and the signals for the different paths are despread in the fingers by the despreaders 141_1 to 141_4 and combined in the MRC portion 142. The detector 22 produces a detection signal DET which in this case is supplied as the reference signal REF to the subtractor 11 in each finger. The subtractor 11 receives the output signal of the main beamformer 6_{M1} to 6_{M4} in the finger concerned and subtracts it from the reference signal REF_1 to REF_4 to produce an error signal ERR_1 to ERR_4. This error signal is used by the adaptation portion to adjust the weights for the main beamformer in the finger.

It will be understood that in the Figure 3 apparatus, because the main beamformers are provided on a per-finger basis, the main beam patterns can be adjusted, if desired, to have narrow main lobes directed closely to their respective desired paths, rather than having to have a large enough width to catch all the paths as in the case of the main beamformer in Figure 2.

It is not always necessary for the initial weights for the different main beamformers to be different from one another. If the best paths are all confined to one assistant beam pattern, all the main beamformers can have their initial weights equal to the weights of the assistant beamformer concerned.

Figure 5 shows a block diagram of a second embodiment of the present invention. This embodiment is also intended for use in a CDMA system which utilises PSAM. Components of the second embodiment which are the same as, or correspond to, components of

the first embodiment are denoted by the same reference numerals.

The first embodiment of the present invention described with reference to Figure 2 adopted a "parallel" approach in which each of the assistant beamformers and the main beamformer has its own individual hardware. In the second embodiment of the present invention, a "serial" approach is adopted, enabling the same hardware to be used to serve, at different times, as assistant beamformers and as a main beamformer.

In the Figure 5 embodiment, a single beamformer 6 is employed which, as described previously, comprises complex number multipliers 8 and a combiner 10. Respective RF signals from the antenna elements to 2_1 to 2_3 are down-converted by the RF down-converters 4 to provide digital I-Q signal pair inputs for the beamformer 6.

An output signal of the path searcher and RAKE combining portion 14 is coupled to an input of a selection switch 30. The selection switch 30 has first and second outputs, the first output being connected to an input of a storing/comparing/selecting portion 26 and the second output being coupled to an input of a detector 22. A detection signal output DET of the detector 22 is coupled to an input of an adaptation algorithm portion 20. An output of the adaptation algorithm portion 20 is coupled to the multipliers 8 in the digital beamformer 6.

The Figure 5 embodiment also comprises a control unit 24 having an input connected to a selection signal output SEL of the storing/comparing/selecting portion 26 and also having a switch control output SW. The Figure 5 embodiment also comprises a weight buffer 28 having N storage regions, where N is the number of assistant beam patterns which the receiving apparatus

is required to produce. In this example, N is 3, so there are 3 storage regions R1 to R3. Each storage region R1 to R3 has a storage capacity sufficient to store a complete set of the weight values for the digital beamformer 6. The weight buffer 28 is, for example, a cyclic shift register. The weight buffer 28 has an input which is coupled to a shift output SHIFT of the control unit 24. The weight buffer 28 also has a weight output WEIGHT which is connected to the complex number multipliers 8 in the digital beamformer 6.

Operation of the Figure 5 embodiment will now be described with reference to Figure 6.

Initially, the selection switch 30 is configured to connect its input to its first output (the output connected to the storing/comparing/selecting portion 26). Also, in the weight buffer 28 the weight settings W_{11} to W_{13} for the first assistant beamformer are held in storage region R1; the weight settings W_{21} to W_{23} for the second assistant beamformer are held in storage region R2; and the weight settings W_{31} to W_{33} for the third assistant beamformer are held in storage region R3.

At the start of a first timeslot TS 1 of the transmission signal received from a wanted user (mobile station), i.e. at time A in Figure 6, the control unit 24 applies a shift signal SHIFT to the weight buffer 28. In response to this signal, the content of the storage region R1 of the weight buffer is transferred to the digital beamformer 6. At the same time, the weight buffer, being a cyclic shift register, shifts the contents of the storage regions R1, R2 and R3 to storage regions R3, R1 and R2 respectively.

At this time, therefore, the weight settings for the first assistant beamformer are loaded into the digital beamformer 6. Thus, a first assistant beam

pattern is effectively formed by the receiving apparatus. This pattern is maintained for pilot-symbol periods 1 and 2 of TS 1.

As before, in each of these pilot-symbol periods the path searcher and RAKE combining portion 14 operates to determine the best available signals (e.g. the four best available signals if the RAKE has four fingers) within the assistant beam pattern. The path searcher and RAKE combining portion 14 combines the best signals, as appropriate, and produces, for each of the first and second pilot-symbol periods of TS 1, an output-signal sample O_{A1} corresponding to the first beam pattern. These two output-signal samples O_{A1} for the first assistant beamformer are transferred via the selection switch 30 to the storing/comparing/selecting portion 26. This portion 26 stores the two samples for later use.

At the end of pilot-symbol period 2 (time B) the control unit 24 produces another SHIFT signal, in response to which the second assistant beamformer weight settings (by this time held in storage region R1 of the weight buffer) are transferred to the digital beamformer 6. A cyclic shift of the weight settings in the weight buffer 28 is also performed, as at time A.

As a result, a second assistant beam pattern is effectively formed in pilot-symbol period 3 of TS 1. A single sample O_{A2} of the output signal for the second assistant beam pattern is taken in this period, and the sample is again stored in the storing/comparing/selecting portion 26.

Next, at time C a further SHIFT signal is produced by the control unit 24, with the result that the weight settings for the third assistant beamformer are transferred from storage region R1 of the weight buffer 28 to the digital beamformer 6. The usual cyclic shift of the weight settings within the weight buffer is also

performed.

In pilot-symbol period 4 of TS 1 a sample O_{A3} is taken of the output signal of the third assistant beamformer and this sample is delivered by the selection switch 30 to the storing/comparing/selecting portion 26.

At the end of pilot-symbol period 4 of TS 1 (time D) a further SHIFT signal is produced by the control unit so that the weight settings for the first assistant beamformer are transferred from storage region R1 of the weight buffer to the digital beamformer, ready for the start of TS 2.

In TS 2 and 3 a similar sequence of operations is performed except that in TS 2 two samples O_{A2} are taken for the second assistant beamformer and in TS 3 two samples O_{A3} are taken for the third assistant beamformer. In this way, it can be seen that, in total over the three timeslots, four samples are taken for each of the first, second and third assistant beamformers.

At the end of pilot-symbol period 4 of TS 3, i.e. when all of the necessary samples have been taken, the storing/comparing/selecting portion 26 averages the four samples taken for each assistant beamformer and compares the averaged samples for the different assistant beamformers. From this comparison, one or possibly two assistant beamformers are selected as producing the best signal or signals, as in the first embodiment. This information is communicated by the portion 26 to the control unit 24 using the SEL signal.

In the control unit 24, if it is found that just one of the assistant beamformers has produced a clear "best" signal, the weight settings for that assistant beamformer are used as the initial weight settings for the main beamformer and, as described previously with reference to the first embodiment, these settings are

provided by the control unit 24 to the beamformer 6. Alternatively, if there are two comparably-good signals from different respective assistant beamformers, an interpolation process based on the respective weight settings of the two assistant beamformers is applied to arrive at the initial weight settings for the main beamformer, as described previously. These weight settings are then applied to the digital beamformer 6.

Once the initial weight settings for the main beamformer have been determined by the control unit 24 in this way, the main beamformer starts to operate using the initial weight settings. The selection switch 30 is changed over so that the path searcher and RAKE combining portion 14 is connected to the detector 22 to form a feedback loop. The adaptation algorithm portion 20 then operates, as described previously, to optimise the weight settings and dynamically update them to meet the prescribed reception criteria.

In the above example there are 3 assistant beamformers and each assistant beamformer processes 4 samples of its output signal over a period of 3 timeslots. Those samples are then averaged to produce an average measure for each assistant beamformer. However, the invention is not limited to this. It is generally desirable for all of the assistant beamformers to sample at least one pilot symbol per timeslot, in case the channel variation from one timeslot to the next is significant. It is also generally desirable to use every pilot symbol which is available for the assistant beamformers, since otherwise the available pilot-symbol periods are not utilised to maximum effect. In some systems, it may also be possible to take just one sample per assistant beamformer, making the averaging step the unnecessary. In this case, though, the risk of an error in the initial weight setting is increased.

The serial approach described with reference to the second embodiment has the advantage of being highly economical in hardware terms. This economy is particularly significant in view of the fact that the path searcher and RAKE combiner portions 14 are expensive components of the receiving apparatus. In the first embodiment, they have a count of four, whereas in the second embodiment they have a count of just one.

Also, it is not necessary to activate the RAKE combining function in the path searcher and RAKE combiner portion 14 during the initial phase when the assistant beamformers are active. In this case, the path searcher function alone can provide a set of per-best-path output-signal samples for the currently-activated assistant beamformer in each sampling period, instead of a combined output-signal sample in which all the best paths are combined.

The main disadvantage of the serial approach is that it has a relatively long convergence time because it is not possible for the same batch of pilot-symbols to be used by all of the assistant beamformers simultaneously.

If desired, in the Figure 5 embodiment more than one beamformer may be provided so that, after the initial weights have been determined, each path can have its own independent main beamformer, as in Figure 3.

Figure 7 shows parts of receiving apparatus according to a third embodiment of the present invention. In this embodiment, a so-called "hybrid" approach, combining the best features of the parallel approach of the first embodiment and the serial approach of the second embodiment, is adopted.

In the third embodiment, a single digital beamformer 6 is provided, made up of the complex number

multipliers 8 and the combiner 10, as in the second embodiment.

In this embodiment, the beamformer inputs are provided via respective switches 34, each having four inputs A1, A2, A3 and M. The A1 input of each switch is coupled directly to an RF down-converter 4 which is in turn coupled to one of the antenna elements 2_1 to 2_3. The A2 input of each switch is coupled to the RF down-converter 4 via a first buffer 32_1. The A3 input of the switch is coupled to the A2 input via a second buffer 32_2 and the M input is coupled to the A3 input via a third buffer 32_3. Each of the buffers 32_1 to 32_3 is constituted identically and introduces a delay equal to (or greater than) the duration of a batch of pilot symbols in a CDMA transmission timeslot.

In the third embodiment, a control unit 36 incorporates the functions of both the storing/comparing/selecting position 26 and the weight buffer 28 of the second embodiment, as well as control functions similar to those provided by the control unit 24 in the second embodiment.

The remaining elements of 20, 22 and 30 in the third embodiment correspond to the same elements in the second embodiment.

Operation of the third embodiment will now be described with reference to Figure 8. Initially, each of the switches 34 is configured to select its A1 input and the selection switch 30 is configured to the position shown in Figure 7 itself which it connects the output of the path searcher and RAKE combiner portion 14 to the input of the control unit 36.

The sequence of operations is commenced (time A in Figure 8) when the first pilot-symbol of a batch PS of pilot symbols in the current timeslot at the A1 input of each switch element appears. At this point, the control unit 36 causes the weight settings for the

first assistant beamformer to be loaded into the complex number multipliers 8 of the digital beamformer 6. The output signal O_{A1} of the path searcher and RAKE combiner portion 14 over the period occupied by the batch of pilot symbols is then stored in the control unit 36.

At the end of the batch PS of pilot symbols (time B in Figure 8) the control unit 36 loads the weight settings for the second assistant beamformer into the complex number multipliers 8, and changes the setting of each switch 34 to select its A2 input. By this time, through the action of the first buffer 32_1 interposed between the A1 and A2 inputs of each switch 34, the original batch PS of pilot symbols appears at the A2 input of each switch 34. The batch of pilot symbols is therefore processed again in accordance with the second assistant beam pattern determined by the weight settings for the second assistant beamformer and, again, the results O_{A2} appearing at the output of the path searcher and RAKE combiner portion 14 are stored in the control unit 36.

Similarly, at time C the control unit 36 loads into the complex number multipliers the weight settings for the third assistant beamformer, and changes the setting of each switch 34 to select its A3 input. At this time, the original batch PS of pilot symbols is appearing at the A3 input of each switch 34, by virtue of the second buffer 32_2 between the A2 and A3 inputs of each switch 34. Accordingly, the original batch PS of pilot symbols is processed again in accordance with the third assistant beam pattern and the results O_{A3} are stored in the control unit 36.

At time D, the stored results O_{A1}, O_{A2}, O_{A3} for the first, second and third beamformers are compared with one another and the initial weight settings for the main beamformer are calculated in the same basic

way as described above for the first and second embodiments. These initial weight settings are applied by the control unit 36 to the complex number multipliers 8, and the switches 34 are reconfigured to select their respective M inputs, whereafter the main beamformer is activated.

At time E the selection switch 30 is changed over so that the output of the path searcher and RAKE combiner portion 14 is connected to the input of the detector 22. In this way, a feedback loop for the main beamformer weight settings is formed comprising the path searcher and RAKE combiner portion 14, the detector 22 and the adaptation algorithm portion 20.

At time E, also, the original batch of pilot symbols, now already processed by each of the three assistant beamformers, is available at the M input of each switch 34. Thus, the main beamformer can start to operate with the original batch of pilot symbols.

As described above, in the third embodiment the use of the buffers 32 enables the three assistant beamformers to use, one after the other, the batch of pilot symbols. Furthermore, the adaptation algorithm portion 20 is able to fine tune or train the weight settings with the aid of the same batch of pilot symbols.

Also, it is not necessary to activate the RAKE combining function in the path searcher and RAKE combiner portion 14 during the initial phase when the assistant beamformers are active. In this case, the path searcher function alone can provide a set of per-best-path output-signal samples for the currently-activated assistant beamformer in each sampling period, instead of a combined output-signal sample in which all the best paths are combined.

The present invention is not limited to being used in CDMA communication systems and can also be used in

time-division-multiple access (TDMA) systems. Figure 9 shows parts of a fourth embodiment of the present invention intended for use in such a TDMA system. In this system, the receiving apparatus is not of the RAKE type and accordingly the path searcher and RAKE combiner blocks 14 used in the first to third embodiments are omitted. In place of these, the fourth embodiment has squaring-operation portions 44_{A1} to 44_{A3} and 44_M connected to the assistant and main beamformer outputs. The squaring-operation portions 44 serve to produce measures of the powers of the beamformer outputs. Instead of the squaring-operation portions 44 it is possible to employ other means of determining signal power, for example means for correlating a predefined synchronisation sequence of the wanted signal. This would have the advantage of eliminating the interference power included with the wanted signal power.

The serial and hybrid approaches described with reference to the second and third embodiments respectively can also be applied in TDMA systems.

The present invention is also not limited to being applied in digital communications systems. For example, in a fifth embodiment of the present invention shown in Figure 10, the present invention is applied to an analog communications system. In this case, the multipliers 8 used in the first embodiment are replaced by attenuators and phase shifters 8'. Similarly, the path searcher and RAKE combiner portions 14 used in the first embodiment are replaced by power measuring portions 44'. The RF down-converters 4 used in the first embodiment are also changed to being corresponding analog elements 4'.

Figure 11 shows the sequence of communications between a mobile station and a base station when the base station grants the mobile station a channel

(traffic or control channel) and that channel is activated.

Firstly, using a dedicated control channel (the random access channel RACH) the mobile station informs the base station that it is requesting a channel. A time T_A later, the base station informs the mobile station, via another dedicated control channel (the access grant channel AGCH), that it is granting the base station a particular channel. The communication from the base station to the mobile station via the AGCH specifies parameters necessary for establishing the channel, such as, for example, the frequency/time/code which has been allocated by the base station to the granted channel concerned.

A time T_T after the transmission of the channel grant information on the AGCH, the mobile station activates the granted channel. From this point onwards, the mobile station transmits information to the base station in predetermined frames. Each frame is divided into 16 timeslots, each timeslot commencing with a batch of pilot symbols P and continuing with user-data or control symbols. For example, T_A may be of the order of 100ms. The timeslot may consist of 20 or 40 symbols, of which four symbols may be pilot symbols. The duration of a complete frame is, for example, 10ms and each time slot is of duration 625μs. In a timeslot of 20 symbols, this equates to a symbol rate of 32Ksymbol/s.

CLAIMS

1. Receiving apparatus, for receiving a transmission signal in a cellular mobile communications system, comprising:

main beamformer means operable to process received signals, representing the said transmission signal, in accordance with a main beam pattern that is determined by beam control information applied thereto, the said main beam pattern being adjusted as necessary during use of the receiving apparatus to facilitate reception of the said transmission signal;

assistant beamformer means operable, in an initial operating phase of the apparatus, to process such received signals in accordance with each one of a plurality of different assistant beam patterns to derive one or more output signals corresponding to the assistant beam pattern concerned, each such pattern being determined by beam control information corresponding individually thereto; and

beam control information setting means operable to employ the said output signals and the said beam control information corresponding respectively to the said assistant beam patterns to make an initial estimate of the said beam control information for the said main beamformer means.

2. Receiving apparatus as claimed in claim 1, wherein the said assistant beamformer means have a plurality of individual assistant beamformer units that are operable simultaneously to process the said received signals in accordance with different respective ones of the said assistant beam patterns.

3. Receiving apparatus as claimed in claim 2, further comprising a plurality of buffers, each having an input connected for receiving a corresponding one of the said received signals and an output connected to an input of the said main beamformer means, for applying the

received signals to the main beamformer means a predetermined delay period after those signals are applied to the assistant beamformer means.

4. Receiving apparatus as claimed in claim 1, wherein the said assistant beamformer means have a single beamformer unit operable to process the received signals in accordance with each of the said assistant beam patterns in a predetermined sequence, the apparatus further comprising output signal storage means for storing, for each assistant beam pattern of the said sequence, one or more samples of the said one or more output signals produced by the said single beamformer unit.

5. Receiving apparatus as claimed in claim 4, wherein the said single beamformer unit is also employed by the said main beamformer means, after the said initial operating phase, to process the said received signals in accordance with the said main beam pattern.

6. Receiving apparatus as claimed in claim 4 or 5, further comprising beam control information storing means for storing the said beam control information corresponding to each assistant beam pattern and for applying to the single beamformer unit the stored beam control information corresponding to each in turn of the said assistant beam patterns.

7. Receiving apparatus as claimed in claim 6, wherein the beam control information storing means comprises a cyclic shift register.

8. Receiving apparatus as claimed in any one of claims 4 to 7, wherein at least two samples of the said output signal are stored for each assistant beam pattern, the apparatus further comprising averaging means for averaging the stored output-signal samples for each assistant beam pattern.

9. Receiving apparatus as claimed in claim 4, further comprising buffer means corresponding to each said

received signal, the said buffer means being operable to apply the same received signals, representing a predetermined portion of the transmission signal, a plurality of times in succession to the said single beamformer unit, the assistant beamformer means being operable to process the received signals applied thereto in accordance with a different one of the said assistant beam patterns at each of the said times.

10. Receiving apparatus as claimed in claim 9, wherein the said buffer means are also operable to apply the same received signals to the said single beamformer unit once again following the said plurality of times, thereby to enable the said main beamformer means to process those received signals in accordance with the said main beam pattern.

11. Receiving apparatus as claimed in claim 9 or 10, wherein the said buffer means comprises switch means having a first set of inputs corresponding respectively to the said assistant beam patterns, the inputs of the first set being connected one to the next by respective buffer elements, and also having an output connected to an input of the said single beamformer unit.

12. Receiving apparatus as claimed in claim 11 when read as appended to claim 10, wherein the switch means have a further input corresponding to the said main beam pattern, which further input is connected to the last input of said first set by a further such buffer element of the said buffer means.

13. Receiving apparatus as claimed in any preceding claim, wherein the said assistant beamformer means includes path searcher means operable, during processing of the received signals in accordance with each different assistant beam pattern, to identify a plurality of best paths for the assistant beam pattern concerned.

14. Receiving apparatus as claimed in claim 13,

wherein the said assistant beamformer means derives such an output signal per best path identified by the said path searcher means.

15. Receiving apparatus as claimed in claim 13, wherein the said assistant beamformer means further includes RAKE combiner means operable to combine signals corresponding to the identified best paths, and the assistant beamformer means derives one such output signal representing those combined signals.

16. Receiving apparatus as claimed in any preceding claim, comprising a plurality of RAKE finger means, each including such main beamformer means, and the said beam control information setting means are operable to make such an initial estimate of the beam control information for the main beamformer means in each such RAKE finger means.

17. Apparatus as claimed in claim 16, wherein the initial estimates for at least two of the RAKE finger means of the said plurality can be different from one another.

18. Receiving apparatus as claimed in any preceding claim, wherein the beam control information setting means are operable to compare one or more predetermined characteristics of the said output signals corresponding to the said different assistant beam patterns to identify one or more best assistant beam pattern(s).

19. Receiving apparatus as claimed in claim 18, wherein the said predetermined characteristics include one or more of the following: a carrier-interference ratio, a signal-noise and interference ratio, a bit error rate, and a signal strength.

20. Receiving apparatus as claimed in claim 19, wherein the beam control information means are operable, if comparison of the output signals in respect of a first one of the said predetermined

characteristics is inconclusive in identifying the said one or more best patterns, to compare the output signals in respect of a second one of the predetermined characteristics different from the said first predetermined characteristic.

21. Receiving apparatus as claimed in any one of claims 18 to 20, wherein, when one best assistant beam pattern is identified, the said beam control information setting means make the said initial estimate the same as the beam control information corresponding that one identified assistant beam pattern.

22. Receiving apparatus as claimed in any one of claims 18 to 21, wherein the beam control information means include interpolation means operable, when two or more best assistant beam patterns are identified, to determine the said initial estimate by interpolating from the beam control information corresponding to the identified assistant beam patterns.

23. Receiving apparatus as claimed in claim 22, wherein in such interpolation the identified assistant beam patterns are weighted according to one of the said predetermined characteristics.

24. Receiving apparatus as claimed in any one of claims 18 to 20, wherein the beam information control means are operable, when two or more best assistant beam patterns are identified, to use the beam control information for each identified best pattern to provide the said initial estimate for at least one RAKE finger means of the said plurality.

25. Receiving apparatus as claimed in any preceding claim, wherein the said transmission signal is a CDMA signal.

26. Receiving apparatus as claimed in any one of claims 1 to 24, wherein the said transmission signal is a TDMA signal.

27. Receiving apparatus as claimed in any preceding claim, wherein the said received signals are digital signals and the said main and assistant beamformer means are digital beamformer means.

28. Receiving apparatus as claimed in any preceding claim, wherein the said assistant beamformer means are operable to process those portions of the received signals that represent pilot symbols included in the transmission signal.

29. Receiving apparatus as claimed in any preceding claim, wherein the said received signals are derived from different respective antenna elements.

30. Receiving apparatus as claimed in claim 29, wherein the number of different assistant beam patterns of the said plurality is greater than the number of antenna elements.

31. Receiving apparatus as claimed in claim 29 or 30, wherein the said antenna elements are spaced non-uniformly one from the next.

32. Receiving apparatus as claimed in claim 29, 30 or 31, wherein at least two of the said antenna elements are arranged in different planes.

33. Receiving apparatus as claimed in any preceding claim, wherein the said beam control information corresponding individually to each assistant beam pattern serves to control one or more of the following characteristics of the assistant beam pattern concerned: the pointing directions, shape and width of the beams embodied in the beam pattern.

34. Receiving apparatus as claimed in claim 33, wherein at least one of the said beam pattern characteristics is different in at least two of the said assistant beam patterns.

35. A method of receiving a transmission signal in a cellular mobile communications system, in which received signals representing the said transmission

signal are processed in accordance with a main beam pattern that is determined by beam control information corresponding thereto, and the main beam pattern is adjusted as necessary to facilitate reception of the said transmission signal;

the method including an initialisation step of: processing such received signals in accordance with each one of a plurality of different assistant beam patterns to derive one or more output signals corresponding to the assistant beam pattern concerned, each such pattern being determined by beam control information corresponding individually thereto; and

employing the said output signals and the said beam control information corresponding respectively to the said assistant beam patterns to make an initial estimate of the said beam control information corresponding to the said main beam pattern.

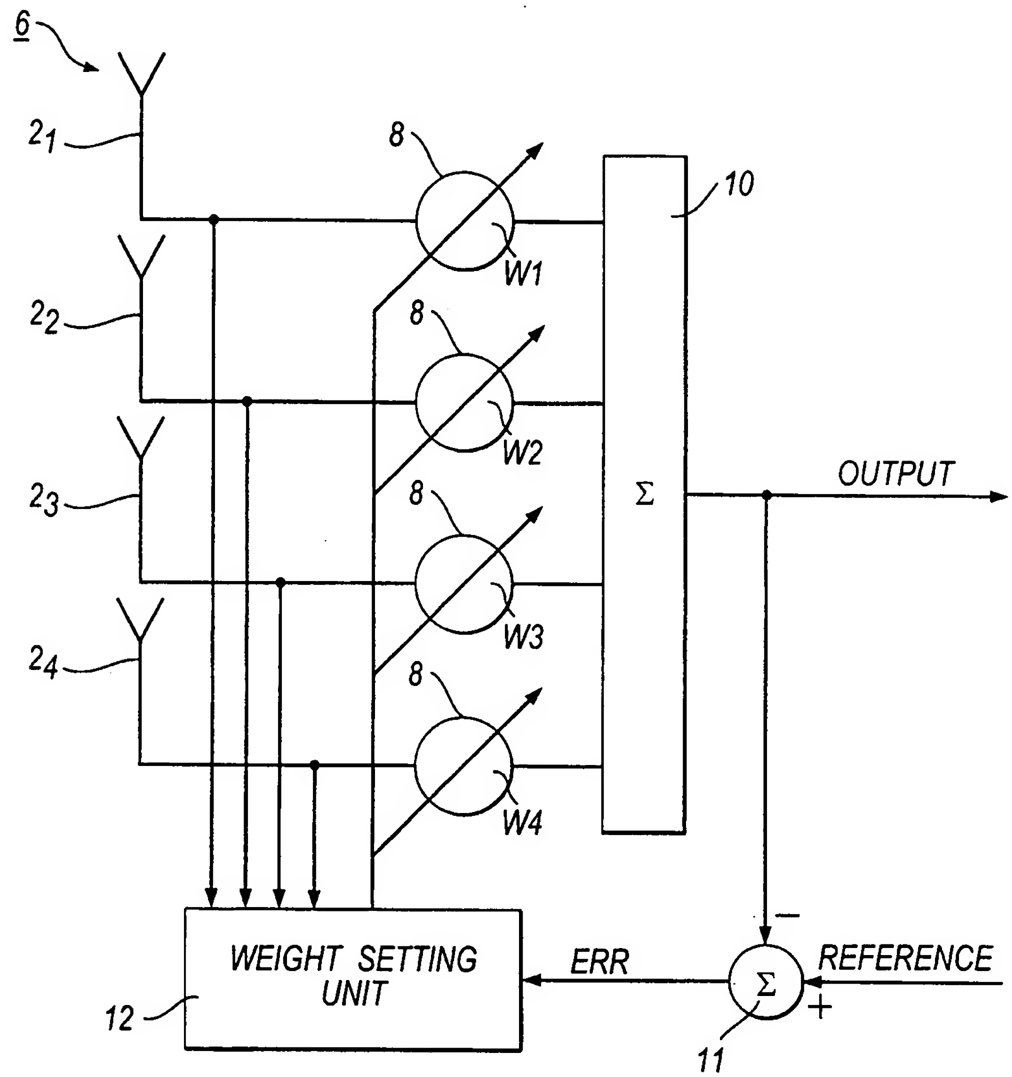

6
2_1
2_2
2_3
2_4
8
8
8
8
W1
W2
W3
W4
10
Σ
OUTPUT
WEIGHT SETTING UNIT
12
ERR
Σ
11
−
+
REFERENCE

Fig.1

2/11

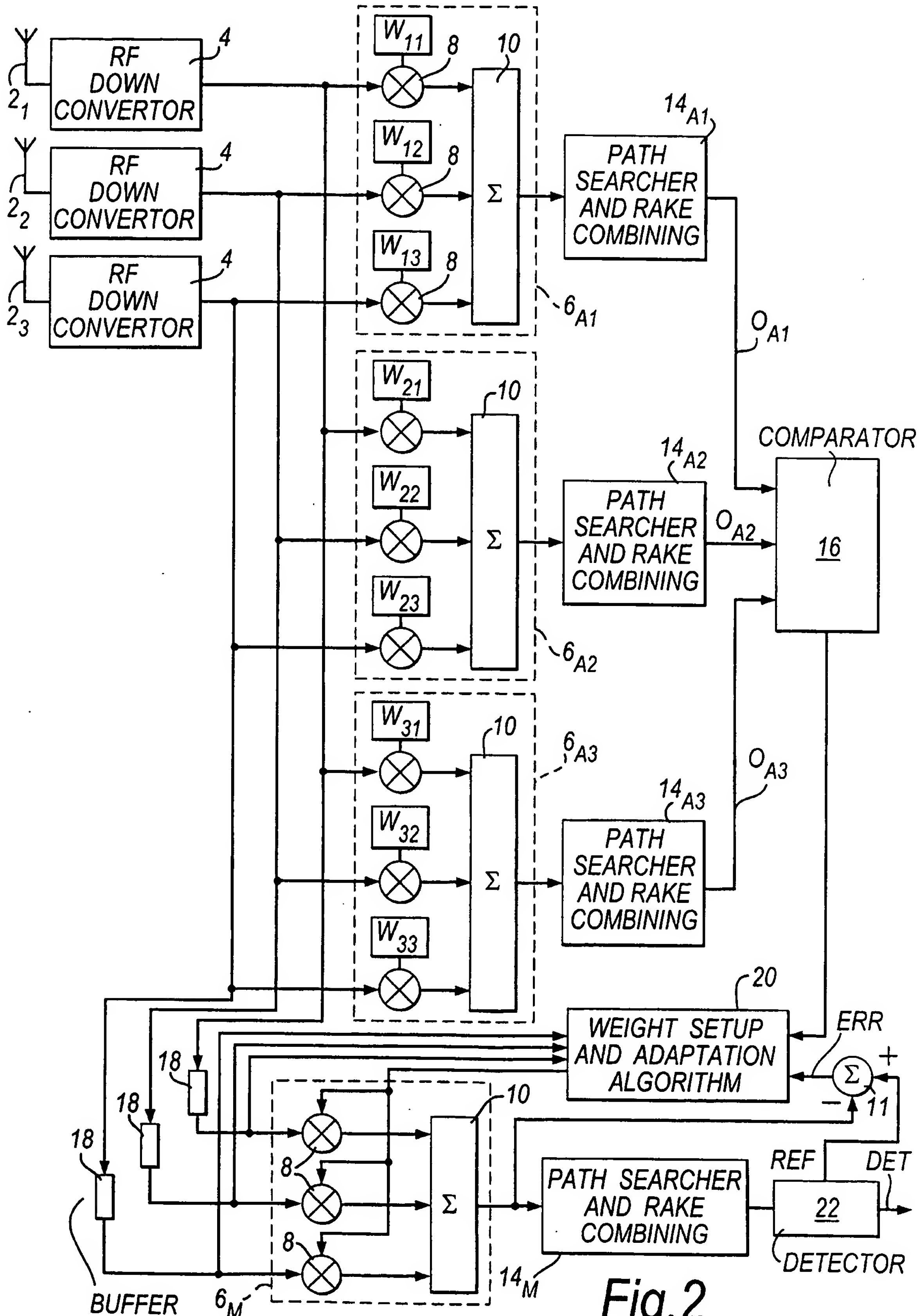

RF DOWN CONVERTOR
4
2_1
2_2
2_3
W_{11}
W_{12}
W_{13}
W_{21}
W_{22}
W_{23}
W_{31}
W_{32}
W_{33}
8
10
Σ
6_{A1}
6_{A2}
6_{A3}
14_{A1}
14_{A2}
14_{A3}
PATH SEARCHER AND RAKE COMBINING
O_{A1}
O_{A2}
O_{A3}
COMPARATOR
16
20
WEIGHT SETUP AND ADAPTATION ALGORITHM
ERR
+
−
11
18
BUFFER
6_M
14_M
PATH SEARCHER AND RAKE COMBINING
REF
DET
22
DETECTOR

Fig.2

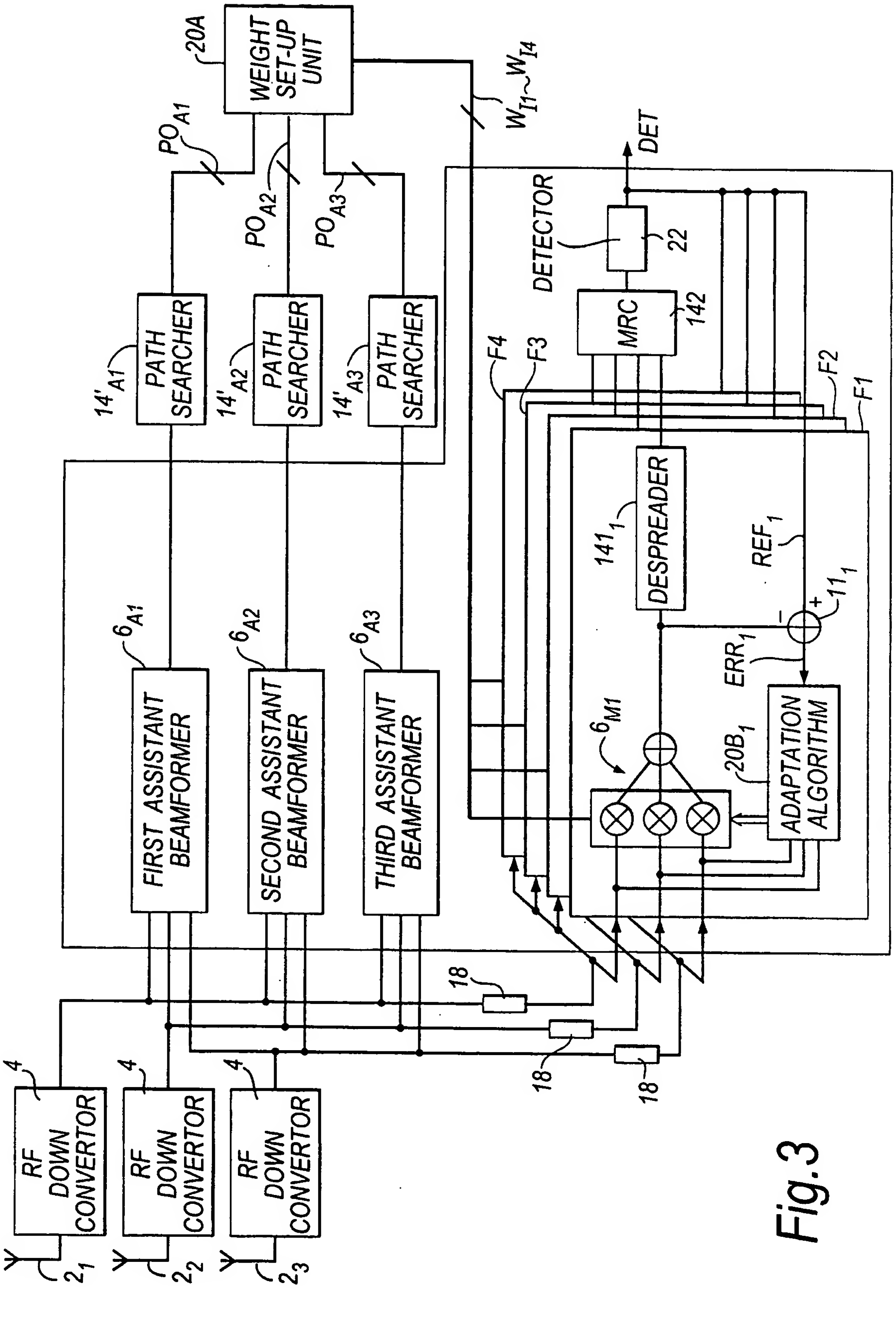

WEIGHT SET-UP UNIT
20A
PO_{A1}
PO_{A2}
PO_{A3}
W_{I1}~W_{I4}
DET
DETECTOR
22
MRC
142
F4
F3
F2
F1
$14'_{A1}$
PATH SEARCHER
$14'_{A2}$
PATH SEARCHER
$14'_{A3}$
PATH SEARCHER
141_1
DESPREADER
REF_1
11_1
ERR_1
6_{A1}
FIRST ASSISTANT BEAMFORMER
6_{A2}
SECOND ASSISTANT BEAMFORMER
6_{A3}
THIRD ASSISTANT BEAMFORMER
6_{M1}
$20B_1$
ADAPTATION ALGORITHM
18
18
18
4
RF DOWN CONVERTOR
4
RF DOWN CONVERTOR
4
RF DOWN CONVERTOR
2_1
2_2
2_3

Fig.3

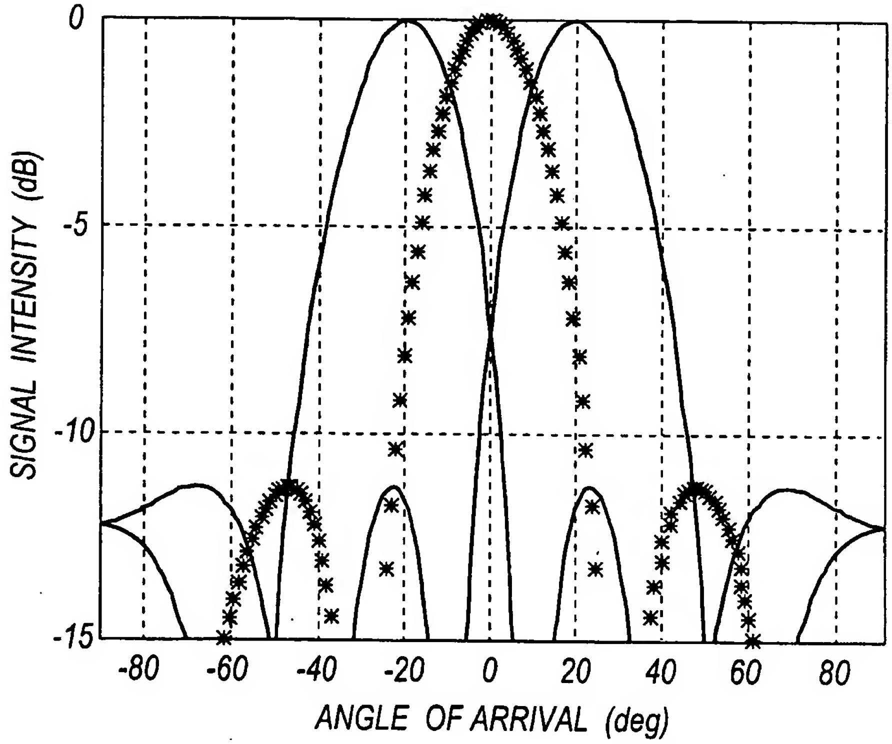

0
-5
-10
-15
SIGNAL INTENSITY (dB)
-80 -60 -40 -20 0 20 40 60 80
ANGLE OF ARRIVAL (deg)

Fig.4

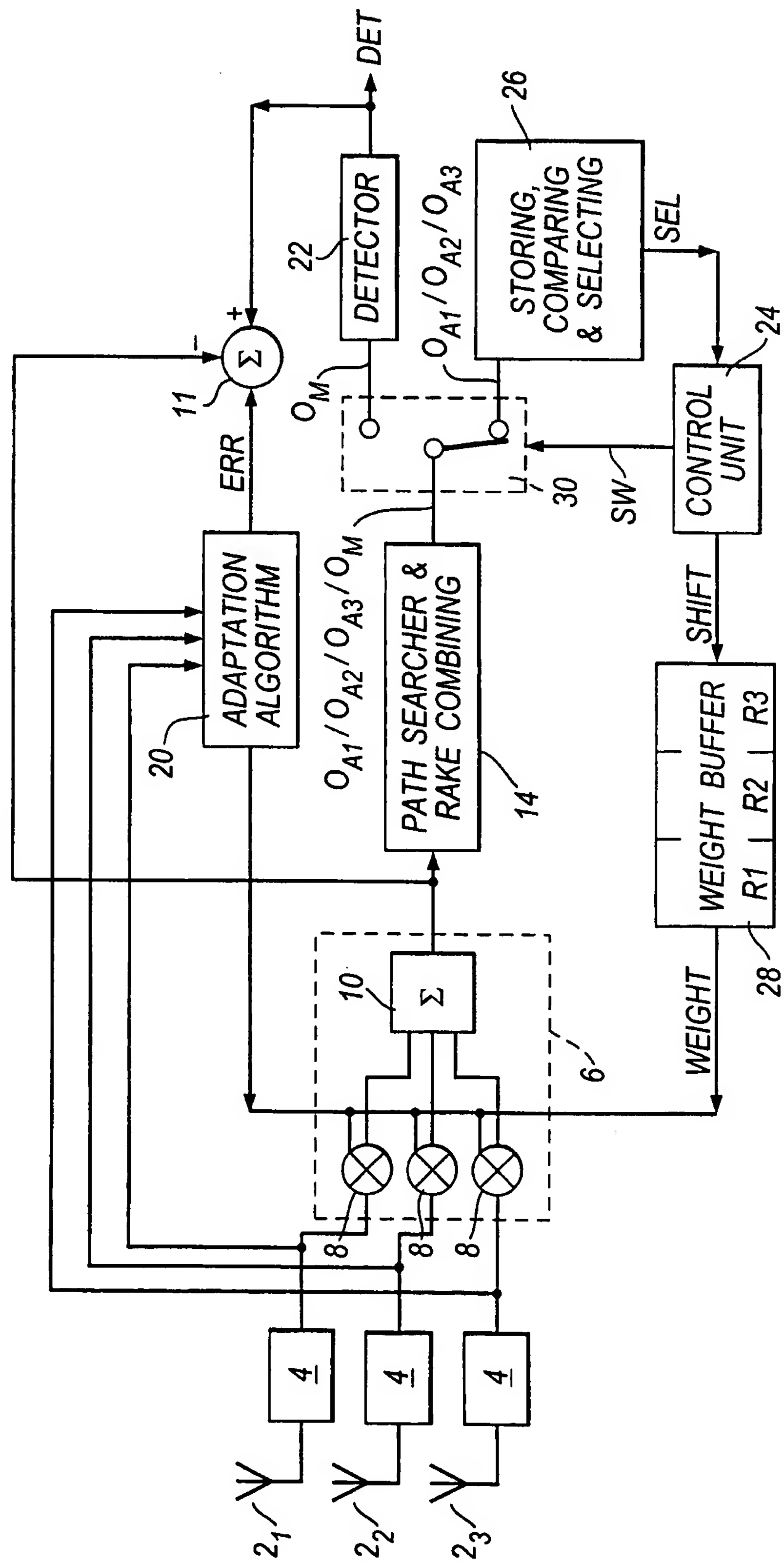

DET
26
22
DETECTOR
STORING, COMPARING & SELECTING
$O_{A1}/O_{A2}/O_{A3}$
SEL
24
CONTROL UNIT
O_M
11
Σ
ERR
30
SW
ADAPTATION ALGORITHM
20
PATH SEARCHER & RAKE COMBINING
14
$O_{A1}/O_{A2}/O_{A3}/O_M$
SHIFT
WEIGHT BUFFER
R1 R2 R3
28
WEIGHT
10
6
8
8
8
4
4
4
2_1
2_2
2_3

Fig.5

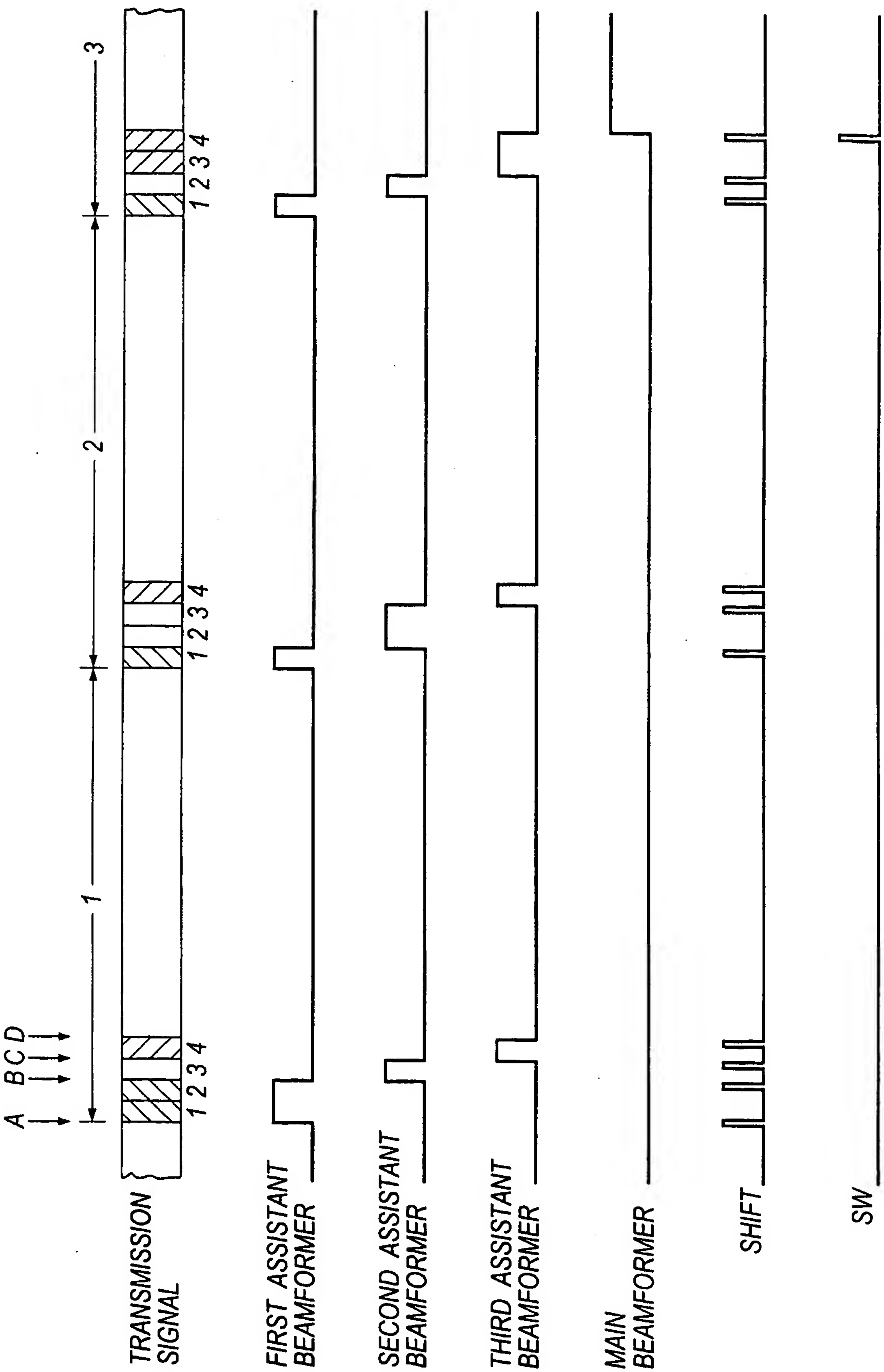

A
B
C
D
1 2 3 4
1
2
3
TRANSMISSION SIGNAL
FIRST ASSISTANT BEAMFORMER
SECOND ASSISTANT BEAMFORMER
THIRD ASSISTANT BEAMFORMER
MAIN BEAMFORMER
SHIFT
SW

Fig.6

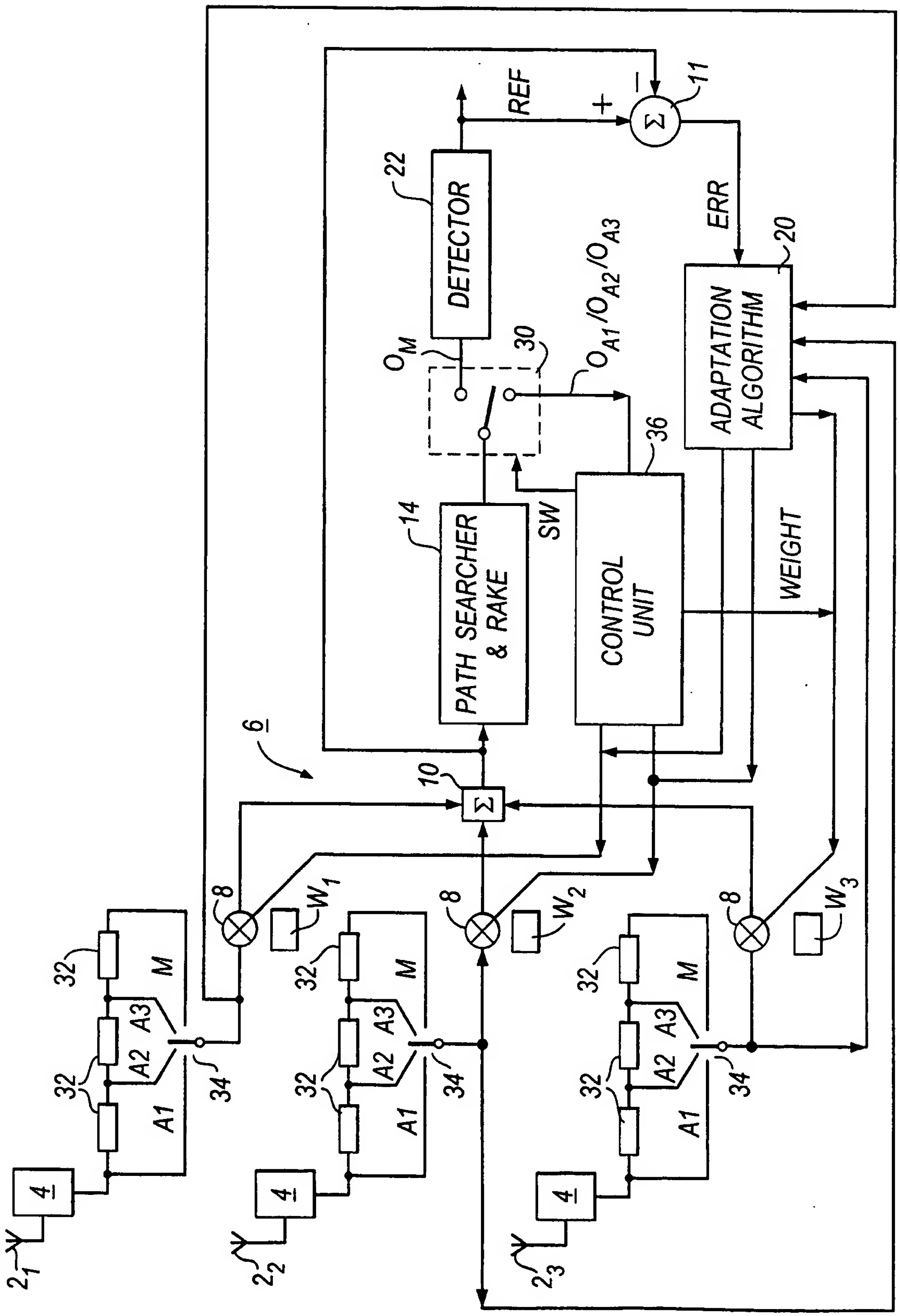

DETECTOR
22
REF
11
ERR
20
ADAPTATION ALGORITHM
O_M
30
$O_{A1}/O_{A2}/O_{A3}$
36
14
PATH SEARCHER & RAKE
SW
CONTROL UNIT
WEIGHT
6
10
8
W_1
W_2
W_3
32
M
A3
A2
A1
34
4
2_1
2_2
2_3

Fig.7

8/11

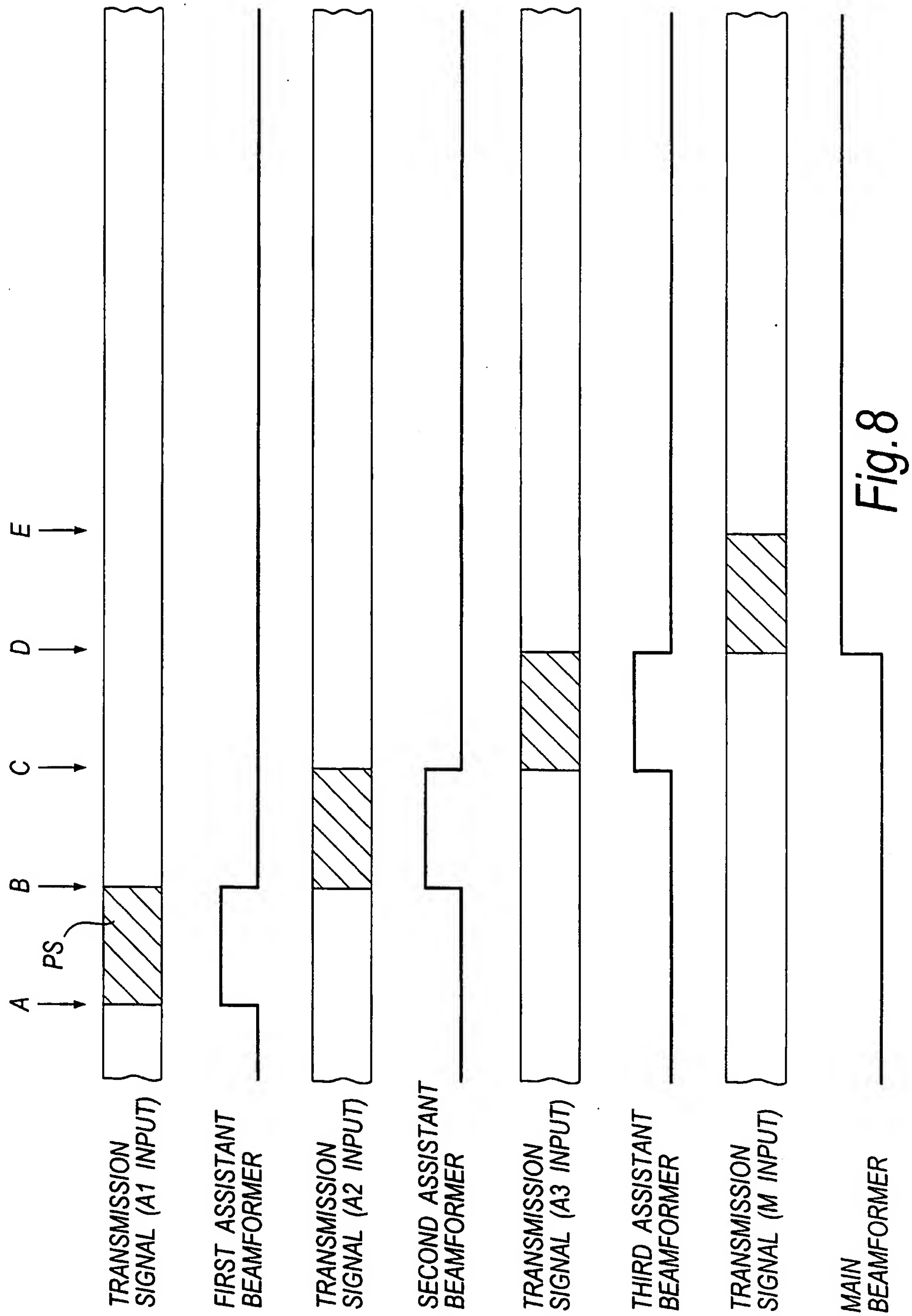
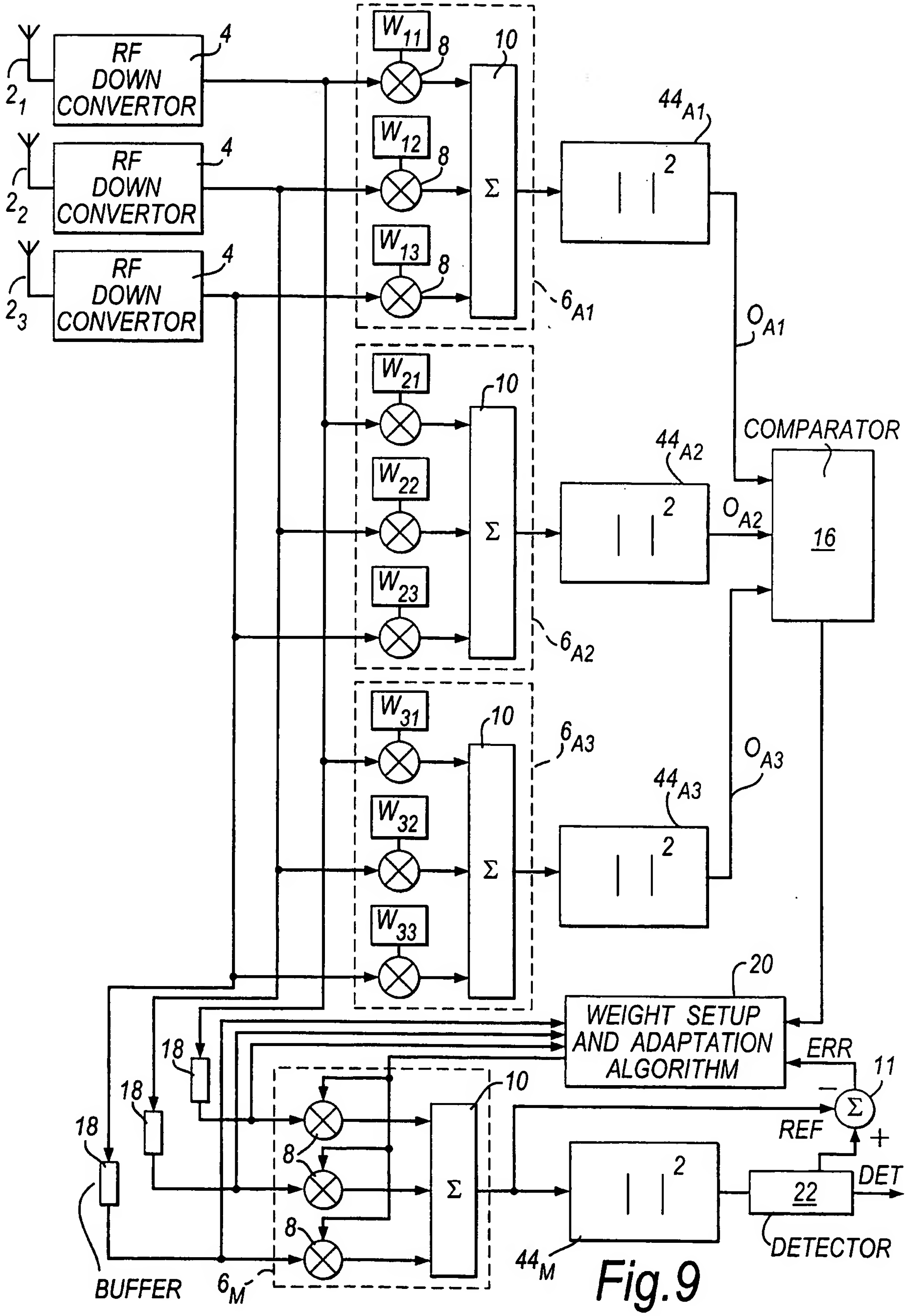
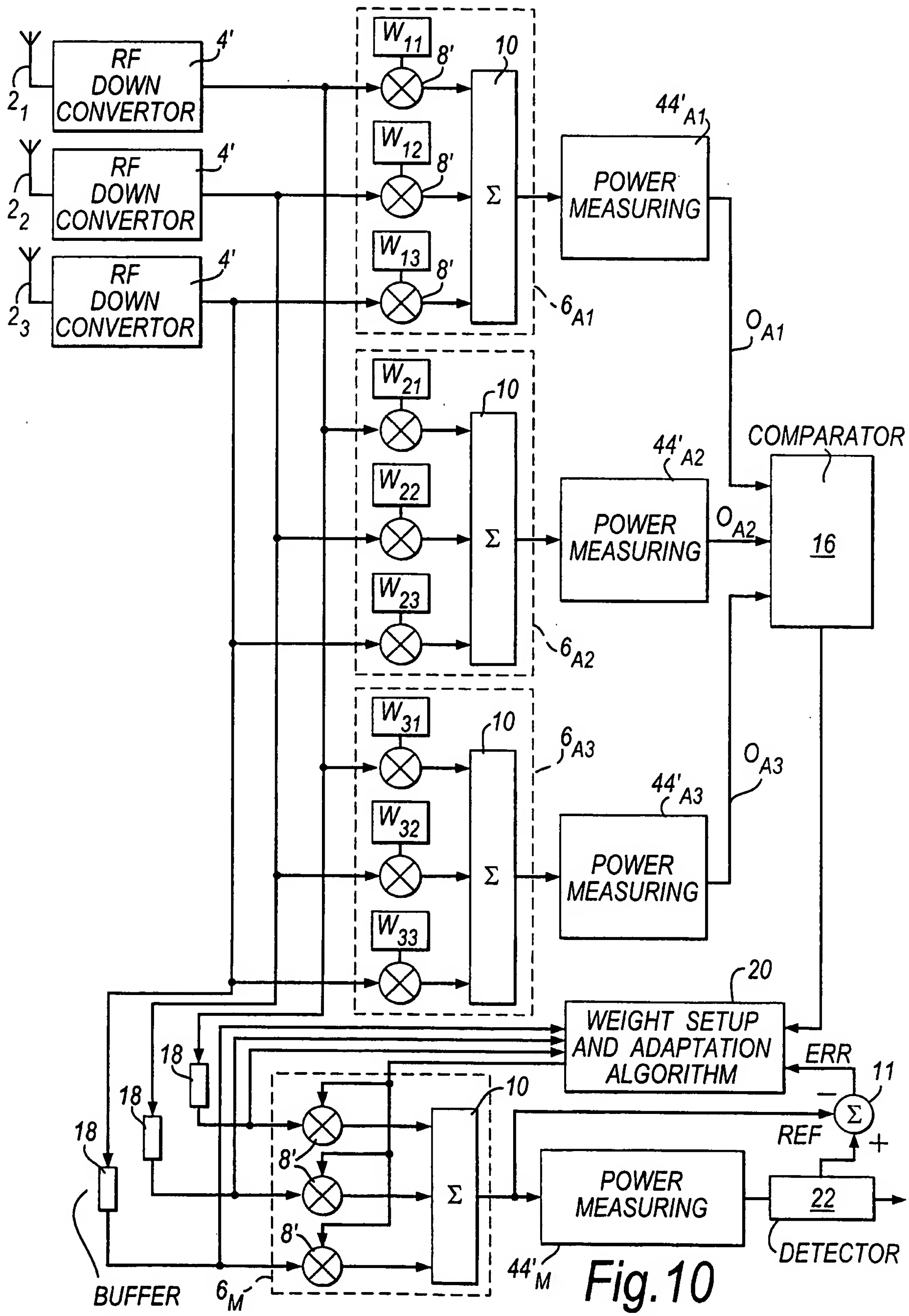

A
B
C
D
E
PS
TRANSMISSION SIGNAL (A1 INPUT)
FIRST ASSISTANT BEAMFORMER
TRANSMISSION SIGNAL (A2 INPUT)
SECOND ASSISTANT BEAMFORMER
TRANSMISSION SIGNAL (A3 INPUT)
THIRD ASSISTANT BEAMFORMER
TRANSMISSION SIGNAL (M INPUT)
MAIN BEAMFORMER

Fig.8



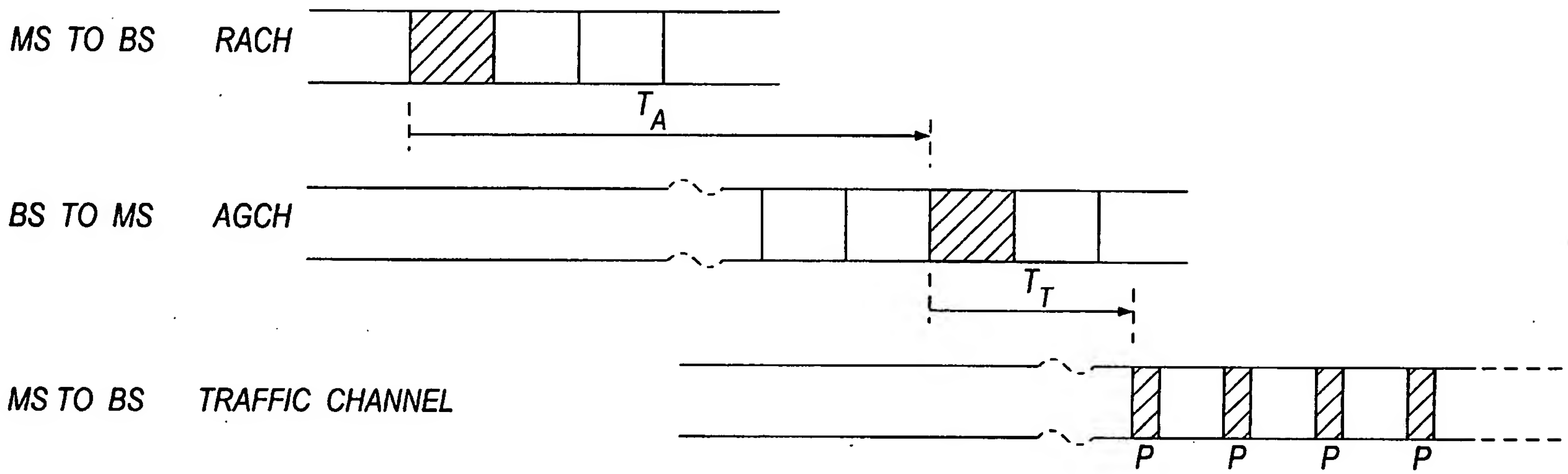
RF DOWN CONVERTOR
4
2_1
2_2
2_3
W_{11}
W_{12}
W_{13}
W_{21}
W_{22}
W_{23}
W_{31}
W_{32}
W_{33}
8
10
Σ
6_{A1}
6_{A2}
6_{A3}
44_{A1}
44_{A2}
44_{A3}
44_M
O_{A1}
O_{A2}
O_{A3}
COMPARATOR
16
20
WEIGHT SETUP AND ADAPTATION ALGORITHM
ERR
11
REF
DET
22
DETECTOR
18
BUFFER
6_M

Fig.9



RF DOWN CONVERTOR
4'
2_1
2_2
2_3
W_{11}
W_{12}
W_{13}
W_{21}
W_{22}
W_{23}
W_{31}
W_{32}
W_{33}
8'
10
Σ
6_{A1}
6_{A2}
6_{A3}
$44'_{A1}$
$44'_{A2}$
$44'_{A3}$
POWER MEASURING
O_{A1}
O_{A2}
O_{A3}
COMPARATOR
16
20
WEIGHT SETUP AND ADAPTATION ALGORITHM
ERR
11
REF
18
BUFFER
6_M
$44'_M$
22
DETECTOR

Fig.10



MS = MOBILE STATION

BS = BASE STATION

RACH = RANDOM ACCESS CHANNEL

AGCH = ACCESS GRANT CHANNEL

P = PILOT SEQUENCE

T_A = TIME TAKEN BETWEEN CHANNEL REQUEST AND BS GRANTING THE CHANNEL

T_T = TIME TAKEN FROM BS GRANTING A CHANNEL AND ACTIVATING THE CHANNEL (TRAFFIC OR CONTROL)

Fig.11

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 99/03839

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04B7/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	NAGUIB A F ET AL: "PERFORMANCE OF WIRELESS CDMA WITH M-ARY ORTHOGONAL MODULATION AND CELL SITE ANTENNA ARRAYS" IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS,US,IEEE INC. NEW YORK, vol. 14, no. 9, 1 December 1996 (1996-12-01), pages 1770-1783, XP000639640 ISSN: 0733-8716 page 1770, left-hand column, line 1 -page 1771, left-hand column, line 8 page 1773, left-hand column, line 7 -page 1774, right-hand column, line 27 figures 2-4	1,35

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
29 February 2000	08/03/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Gkeli, M

2

INTERNATIONAL SEARCH REPORT

Inter. .onal Application No
PCT/GB 99/03839

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	MIURA R: "SPATIAL UTILIZATION AND SUPPRESSION OF MULTIPATH SIGNALS BY MAXIMAL-RATIO-COMBINING DIGITAL BEAMFORMER FOR MOBILE RADIOS" IEICE TRANSACTIONS ON COMMUNICATIONS,JP,INSTITUTE OF ELECTRONICS INFORMATION AND COMM. ENG. TOKYO, vol. E81-B, no. 4, 1 April 1998 (1998-04-01), pages 806-810, XP000780476 ISSN: 0916-8516 page 806, left-hand column, line 1 -page 807, left-hand column, line 42 figure 1	1,35
A	WO 98 27669 A (CWILL TELECOMMUNICATIONS INC) 25 June 1998 (1998-06-25) page 8, line 9 -page 13, line 11 page 13, line 21 -page 14, line 4 figures 6,7,9	1,35
A	US 5 649 287 A (FORSSEN ULF GOERAN ET AL) 15 July 1997 (1997-07-15) column 1, line 47 -column 2, line 12 claim 1	1,35

2

Form PCT/ISA/210 (continuation of second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Information on patent family members

Inter. ...nal Application No
PCT/GB 99/03839

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		EP 0953235 A	03-11-1999
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		WO 9630964 A	03-10-1996